

NEAR-EARTH OBSERVATIONS BY SPREAD TELESCOPES

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Abstract

We suggest the all-sky survey at the International Space Station by four little wide-angle telescopes with polarization filters and CCD-arrays spread by several meters one from another. The video information processing will be carried out by real-time multiprocessor system on the board of the station. This experiment would allow to observe the sunlit space debris and meteoroids of centimetre size with their distances and velocities estimations at the distances up to 20 km from station and to investigate the interplanetary and interstellar medium by the making of polarization sky maps and detecting the weak-contrast features on it.

1 INTRODUCTION

The investigations of sky background that basically consists of zodiacal light are difficult to conduct on the ground because of sufficient contribution of the light of other sources and zodiacal light itself (Bernstein *et al*, 2002) scattered in the atmosphere. The translucent high-latitude cirruses found by IRAS were observed in the visual by Cawson *et al* (1986). Since the scattered light is sufficiently polarized, these features are better to search for on the polarization sky maps. The space experiment with polarization sky survey using wide-angle telescopes and CCD-arrays would allow to investigate the distribution and properties of interplanetary dust, the size, shape and orientation of dust particles.

Another problem related with prolonged polarization background mapping is the possibility of supernova echoes discovering and investigation. The polarized spots with several years variability should be observable (Maslov, 2000) around the locations of supernovas that were observed

several centuries ago. Observations of these spots would give the information about interstellar medium of our Galaxy. Search for these objects for nonpolarized light was conducted by Van den Bergh (1966) with photographic plates and brought the negative result, but using the modern technique and image processing methods allows to move forward in this question.

Radar stations of space control are regularly watching for several thousands spacecrafts and their fragments with sizes more than 20 cm. The smallest size particles were registered by the collisions with film screens (LDEF satellite) and spacecrafts surfaces. But experimental data about most dangerous for spacecrafts medium-sized (about 1 cm) particles practically are absent.

2 EXPERIMENT DESCRIPTION

The choose of International Space Station (ISS) for this experiment is made by three reasons:

- Near-Earth medium watching near the ISS orbit allows to estimate the statistical parameters and to watch for the bodies dangerous for the station without additional assumptions about their space distribution;
- The size of the ISS allows to spread the telescopes for triangulation;
- Installation of the devices on often-visited station simplifies the changes of the data processing program.

The main three goals of the experiment are:

- Investigations of distribution and properties of dust in the Solar System and Galaxy;
- Obtaining the data about space debris and meteoroid particles of centimetre size near the ISS orbit;
- Discovering and observations of asteroids, comets and variable stars.

The idea of the experiment follows. Four small telescopes with $\sim 8^\circ$ field of view installed on ISS, watching at the same direction and observed the sky by using the continuous station rotation with the angular velocity about $\sim 4^\circ/\text{min}$. The information processing of CCD-images is being done by on-board computers in real-time mode.

The light sources coordinates comparison with stars catalogue allows to determine the exact telescopes orientation, to find unknown sources and to measure their position. The difference of these positions measured on different telescopes allows to determine the distance to the object.

The reasons to use four telescopes are following:

- using of two or more telescopes spread by several meters give the possibility to determine the distance to the particle;

- the registration of the track of fast-moving object by two telescopes with opposite CCD regimes ("exposition" on the first and "reading" on the second and vice versa) allows to determine the angular velocity of the object;
- using the different axes direction of the polarizing filters of the telescopes, we can measure the linear polarization both point and extended sources;
- the work failure of one telescope does not bring sufficient change for the worse of the quality of the information remaining the experiment conduction possible;
- the measurements exactness is better, the probability of space debris or meteoroid discovering or unusual event (short-time burst, for example) observation increases;
- the extension of observable sky area is possible.

The telescopes are installing in pairs on two platforms with vertical (relatively Earth) axis of rotation. The telescopes are watching at one direction by the angle about $30-60^\circ$ to the zenith. The distance between platforms should be not less than 5 m. The platforms are turning the telescopes to the required sky region not emitted by the Sun.

3 APPARATUS DESCRIPTION

The apparatus complex consists of two same devices. The mass of each one is not more than 40 kg, the size is $940 \times 550 \times 550 \text{ mm}^3$, that makes their transfer and installation on the International Space Station possible.

The telescopes are developed in Space Research Institute basing on Star Sensor (Ziman, 1994) that is successfully working now on geostationary communication satellite "Yamal 100". The basic parameters of the telescopes are shown in the Table 1. The telescopes are able to work at angles down to 30° from the Sun and from the Earth horizon. Adding to the video information, they supply the parameters of each image orientation, that is simplify the further information processing.

Table 1: Telescopes characteristics

Lens diameter	26 mm
Focal distance	58 mm
Visible area	$8^\circ \times 8^\circ$
Spectral range	0.5 – 1.0 mkm
CCD format	512×512
Angular resolution	$1'$
Information reading period	1 sec
Noise of reading	$100e^-$

The Information Processing and Saving Device is the special board computer being developed in Space Research Institute. It is consisted of:

- two processors of Intel-486 type with the frequency 66 MHz;
- energy-independent flash memory not less than 8 GBit;
- special modules based on programmed logical matrixes for fast image processing.

One such device can process information from two telescopes. If we use second device for two telescopes, it will be reserve one or we will have the possibility of processing programs debugging and comparison. The basic way to pass the information to Earth and programs edition is their copying using the ISS server and changeable information holders.

4 ALGORYTHMS AND PRINCIPLES OF INFORMATION PROCESSING

The input information flux is the sky images made by four telescopes each second. This flux fulfils the memory of computers at several minutes, that's why the information compression is necessary. It is better to do it in order to have the complete astronomical data (such as maps, catalogues, lightcurves etc.) at the output. The sources in the images can be classified:

- by the extension:
 - *point sources*: the stars and star-like objects (for 1'-resolution);
 - *tracks*: the trace as a straight line made by moving object;
 - *extended sources*: the source with angular size from 1' to several degrees;
 - *background*: the source with angular size more than visible area.
- by the time averaging:
 - *model*: given initially, with parameters correction while the experiment if necessary;
 - *momentary*: present just in one image;
 - *current*: present on the map obtained by the images addition at the single sky survey near the source;
 - *seasonal*: present on the map obtained by the images addition during several months of work (until the data passing to Earth).

The tracks and point sources information will be saved in the catalogs and the extended sources and background - in the 2'-resolution sky maps. Finally, we will obtain the following information:

- last 200 sky images;
- point momentary sources catalogue;
- point current sources catalogue with variability data;

- current sky map;
- tracks catalogue;
- seasonal sky map;
- current maps of some sky regions;
- some sky images.

The apparatus model is given by "dark image", "flat field image" and point spread function (PSF) of point source depending on the orbital declination where the survey was made.

The computer memory is holding the background sky map and stars catalogue that are the sky model for given spectral region. The deflections from this model are recording during the survey, that makes the search for new and variable sources easier. The model image is the sum of background map and point sources with account of PSF.

We suggest the following processing sequence:

- correction of output sky images by "dark image" and "flat field image";
- subtraction of model image with the model point sources brightness correction;
- photometric calibration by the model stars in the visible area;
- the search for tracks and new point sources in images with subtracted model and their include to the tracks and point momentary sources catalogues;
- the creation of current sky map with the size about $10^\circ \times 10^\circ$ using the images with subtracted tracks and point momentary sources;
- the search for weak tracks, stars and extended sources in the current map;
- the information about brightness of sky regions out of current map is including to the seasonal map.

The seasonal map of the whole sky with $2'$ -resolution requires about 200-300 MBytes of memory for each telescope, if not to take the compression into account. The apparatus parameters and sky model are being corrected during the time of experiment and changing after passing the data to Earth. Polarimetric and parallactic measurements are made basing on the maps and catalogues obtained by different telescopes.

5 EXPECTED RESULTS

The exactness of single position measurement of an object relatively the stars is $1'$. Since the stationary and slowly moving objects are being recorded about 100 times at one crossing of visible area, the average-squared exactness can reach $6''$. The same exactness can be reached for

track position measurement perpendicular its direction, since this estimation is made by about 500 pixels.

The sensitivity of the telescopes (by S/N level equal to 1) will be about 10^m for point objects. The exactness of photometric measurements for bright star-like objects will be about 10 percents. The magnitude of the object present in all images obtained during 2-minute survey, and magnitude of the track can be estimated with exactness $0.01 - 0.02^m$.

The magnitude of space debris or meteoroid with albedo about 0.1 and the size D , flying at the distance r with tangential velocity v_t can be estimated by using Bagrov and Vygon's (1998) formula:

$$m_* = -31.1 + 2.5 \lg \left(\frac{r^2}{D^2} \frac{v_t}{r} \frac{1}{\beta} \right), \quad (1)$$

where β is the angular size of one image pixel which is equal to about 3×10^{-4} . Corresponding to this formula, fragment with size equal to 1 cm, flying at 20 km from ISS with velocity 40 km/s will be recorded by the telescopes as a 10^m -track, i.e. with S/N ratio equal to 1. With the velocity or the distance decrease the S/N ratio will rise back proportional to these parameters.

If we increase the distance between the telescopes to 5-6 meters, than the parallax of the fragment at the distance equal to 20 km will reach $1'$ and it will be possible to measure it with 10-percent uncertainty.

The angular velocity of slow moving (from 0.001 to $1^\circ/\text{sec}$) fragments can be measured by the displacement of the object in different images. Having measured the angle between the tracks recorded by CCD-matrixes of two telescopes (in "exposition" and "reading" regimes) we can determine the angular velocity of fast moving (from 0.1 to $8000^\circ/\text{sec}$) fragments. The velocity of meteoroid equal to 40 km/s can be measured from the distance 300 meters!

Thus, the apparatus will be able to find and measure the brightness, angular velocity and distance and estimate the size of all space debris and meteoroids larger than 1 cm, flying at the distances from 1 to 20 km. If the flux of such fragments is dangerous by possible collisions with the station one time per 10 years, than they will be revealed by this apparatus complex several times per day.

Polarimetric observations will be conducted by the comparison of object brightness at four telescopes with different polaroid axes. For extended objects with size more than 1° it is possible to measure polarized light with the intensity equal to 10^{-4} from the background (Sholomitskii *et al.*, 1999), using the large number of pixels. Sky mapping prolonged for the several years would decrease this value for one more order and to investigate the detailed features of Galactic background and zodiacal light variations.

6 CONCLUSION

The experiment would allow to obtain:

- distribution and scattering parameters of interplanetary and interstellar dust by the prolonged regular polarimetric sky mapping;
- statistical estimations of concentration, velocities and sizes of space debris and meteoroids near to International Space Station orbit;
- data about Novas at early stages before the registration by ground-based observatories (especially at low angular distances from the Sun) and statistical characteristics of bursting and variable stars.

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